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CREW TRAINING AND THE RELIABILITY OF
A BATTALION FIRE SUPPORT SYSTEM

by

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March 1991

Thesis Advisor J. D. Esary

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By using a transformation of the training level, as measured by a score on a qualification test, into a crew component reliability, overall fire support system reliability can be computed, and the effect of training predicted. The decision maker (commander) can use the result as a reference in evaluating unit combat ability and in managing unit training and equipment maintenance.

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Crew training and the reliability of a battalion fire support system

by

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Major, Republic of Korea Army
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requirements for the degree of

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ABSRACT

A method for incorporating crew training level into an analysis of the system reliability of a field artillery battalion fire support system is developed. The crew of an equipment can be regarded as a component acting in series with the equipment, which itself has a hardware reliability.

By using a transformation of the training level, as measured by a score on a qualification test, into a crew component reliability, overall fire support system reliability can be computed, and the effect of training predicted. The decision maker (commander) can use the result as a reference in evaluating unit combat ability and in managing unit training and equipment maintenance.

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I. INTRODUCTION

A. BACKGROUND

Research on the reliability of electrical and mechanical systems is extensively developed. The application of this research to military systems has been limited and is missing an important element, the effect of the crew training. Military commanders are interested in the effect of training on their units' combat ability, because increasing training is much easier than changing equipments, especially in a country in which labor costs are low. So, in addition to checking equipment, they often inspect crew training levels to manage their units effectively. Also, they try to save finances and increase combat strength by analyzing and reacting to the inspection result. Even so, data for the separate components does not give any overall information on the situation of the unit as a system.

Success on today's battlefield requires a well trained combined arms team. Field artillery is one of the members of this team [Ref. 1]. The field artillery battalion (FAB) is a typical fire support system. Since the fire support system (FSS) has many equipments, reliability concepts are very useful in analyzing system effectiveness.

Each equipment of the fire support system has a hardware reliability. The crew of each equipment may or may not operate it successfully. The probability of successful operation is related to the training level of the crew. The crew of the equipment can be regarded as a component acting in series with the equipment. This permits the inclusion of crew performance into block diagrams for the success of the battalion on various fire support missions. A method for incorporating the effect of training into the reliability analysis of the battalion fire support system is the subject of this thesis.

For each section of the fire support system (FSS) a component block diagram will be constructed. These block diagrams will include crew performance components. Even though the equipment is reliable, if the crew's ability to operate the equipment is poor, the equipment doesn't work effectively. So the commander does his best to increase the combat ability of his subordinates. The probability of mission success of the crew is related to the current training level of the crew. This training level can be measured by a test. But, since the test result can not guarantee an equivalent level of mission success, a method is needed to formulate the random factor.

B. THESIS SCOPE

The field artillely battalion organization and fire support system are reviewed in general in Chapter II. Block diagrams of the FSS based on tactical missions are developed in Chapter III. Modeling methods for tactical situations will be described in Chapter IV. Additionally, a method to formulate the relationship of training level and crew success will be described there. Chapter V contains the actual implementation of the reliability model. Also cost effectiveness considerations are briefly mentioned.

II. FIELD ARTILLERY ORGANIZATION AND FSS

The mission of field artillery is to destroy, neutralize, or suppress the enemy by cannon, rocket, and missile fires and to assist in integrating fire support into combined arms operations [Ref. 2: pp. 1-1]. Field artillery is usually organized in battalion units. A typical field artillery fire support system (FSS) is constructed from within the field artillery battalion. The field artillery battalion carries out basic firepower support missions through the FAB fire support system.

A. FIELD ARTILLERY BATALLION

Field artillery weapon systems currently available within the general infantry division are 155 mm and 105 mm howitzers. The divisional field artillery battalion conducts combat operations as an organic unit of division artillery or as a member of a separate brigade. The nondivisional battalion conducts operations as a member of a field artillery brigade or has been assigned a tactical mission supporting a maneuver force or reinforcing another artillery unit [Ref. 3 : pp. 3-5]. The field artillery battalion must provide continuous and timely field artillery firepower and provide its component of the field artillery communications, survey, and target acquisition systems. Also it must plan and coordinate fire support and help integrate it into battle plans and provide fire support personnel to maneuver units if appropriate [Ref. 3 : pp. 3-6]. Field artillery battalions are usually organized into a headquarters/headquarters battery and three cannon batteries.

The headquarters/headquarter battery includes general staff sections and special administrative and logistics departments. The battalion fire direction center (BN FDC) in the operations department controls all subordinate fire support systems and reinforcing fire support systems to provide the supported unit with appropriate firepower.

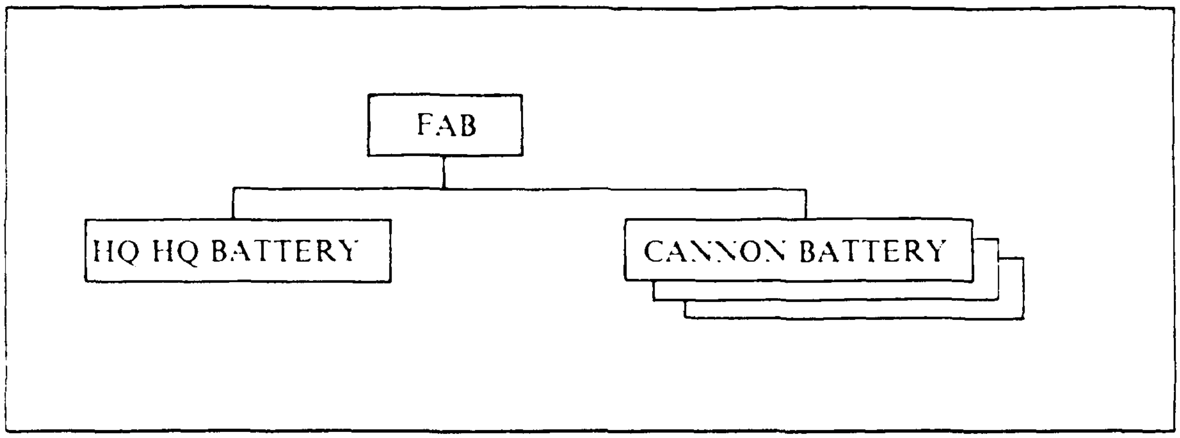


Figure 1. The basic field artillery battalion organization

B. CANNON BATTERY

A field artillery cannon battery is the firing element of the cannon battalion. It has the personnel and equipment necessary to provide continuous fire support [Ref. 2: pp. 1-1]. The three cannon batteries have identical organization. A cannon battery consists of a battery headquarters and a firing battery. The battery headquarters has the personnel and equipment to perform food, supply, communications, nuclear-biological-chemical (NBC), and maintenance functions [Ref. 2: pp. 1-6]. During operations three or four forward observers are detached to the front area unit. The firing battery consists of the battery fire direction center (FDC), an ammunition section (AMM) and six gun sections. A cannon battery is a basic fire unit for fire-for-effect (FFE) missions against an area target. Its fire support system can be controlled by the battalion fire direction center when a battalion concentrated fire support mission is required.

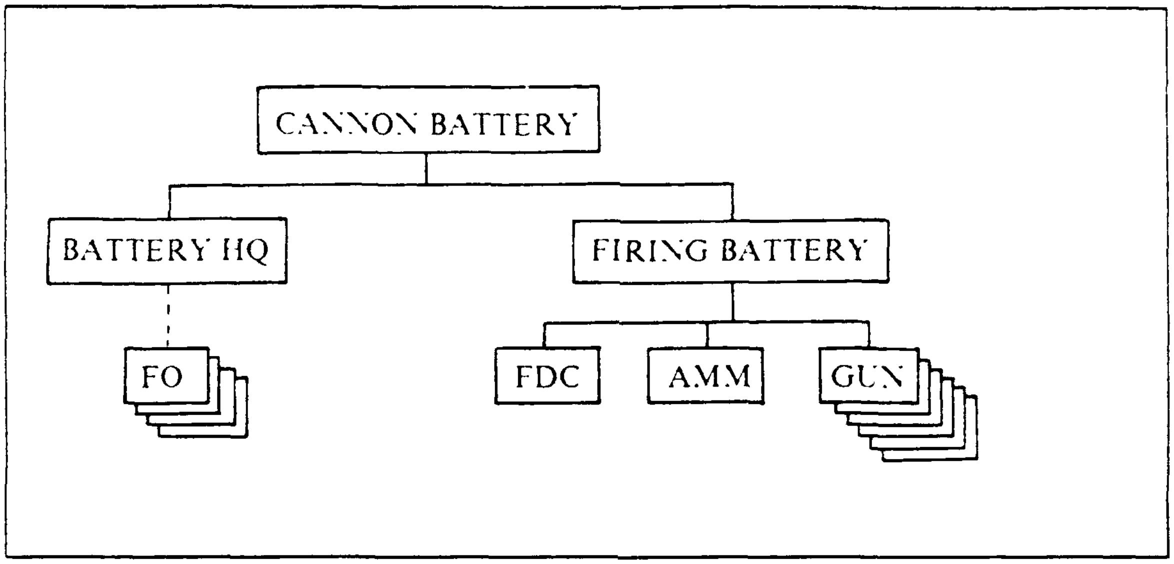


Figure 2. The basic cannon battery organization

C. FIRE SUPPORT SYSTEM KEY ELEMENTS

The FSS structure of a field artillery battalion will be described in detail in Chapter III. The most effective method of accomplishing the field artillery fire support mission is through the coordinated employment of all elements of the field artillery system. These elements are target acquisition, gunnery, weapons and ammunition, and command and control. The fire support system key elements are gunnery and weapons. A field artillery FSS gunnery team consists of the observer, the fire direction center (FDC), and the firing sections, all linked by an adequate communications system [Ref. 4 : pp. 1-1]. Each section includes the personnel and equipments to determine firing data and to fire the guns.

1. Forward observer section

The observer and/or target acquisition assets serve as the eyes and ears of all indirect fire systems. An observer detects and locates suitable indirect fire targets within his zone of observation. There are several kinds of observers conducting similar tasks, but the forward observer (FO) is the most important for divisional field artillery. A forward observer section consists of a crew team with observing equipment, a radio and possibly a sound powered phone. In this section the crew team consists of a forward observer, a radio operator, and a wire operator.

2. Fire direction section

The FDC is the control center, or brains, of the gunnery team and is a section of the firing battery headquarters in the cannon battery [Ref. 4 : pp. 4-1]. The FDC personnel receive the fire request from the forward observer (FO) and process the target information by using tactical and technical fire direction procedures. Then, they issue fire commands to the firing battery weapons designated to fire the mission. The battery FDC normally conducts technical fire direction by using the battery computer system. The battalion FDC mainly conducts tactical fire direction or technical fire direction.

Technical fire direction is the process of converting mechanical characteristics (muzzle velocity, propellant temperature, and projectile weight), meteorological information and target location to firing data. Tactical fire direction includes processing calls for fire and determining the appropriate fire method, ammunition expenditure, units to fire, and time of attack. The FDC is organized to facilitate 24-hour operation. This section includes a crew team which consists of a computer operator, a horizontal control operator, a vertical control operator, a radio operator and a wire operator. Its key equipments are a radio (V-46), a sound powered phone (SPP) and a computer system.

3. Howitzer section (gun)

The howitzer sections are the delivery means, or brawn, of the gunnery team. They apply the fire commands, sent by the FDC, and fire the weapons [Ref.3 : pp. 4-2]. This section includes a howitzer, a sound powered phone (SPP) ar a crew team which

This section includes a howitzer, a sound powered phone (SPP) and a crew team which consists of several gunners.

The key elements of each section contribute to the block diagram of the FSS. All components of the FSS are connected by the communitions links and all members of the gunnery team must aggressively ensure that adequate communications are established and maintained at all times. The battalion fire direction center uses the fire control communication net to control all subordinate fire support systems.

III. BLOCK DIAGRAMS OF THE FIRE SUPPORT SYSTEM

A. THE BASIC FSS STRUCTURE OF A FAB

A battalion fire support system is composed of a battalion fire direction center (FDC) and the subordinate battery fire support systems. A battery fire support system is usually divided into three main sections; forward observer (FO), fire direction center (FDC) and WEAPONS , each with integral communications. The battalion fire direction center controls the battery fire support systems by controlling the batteries' fire direction centers.

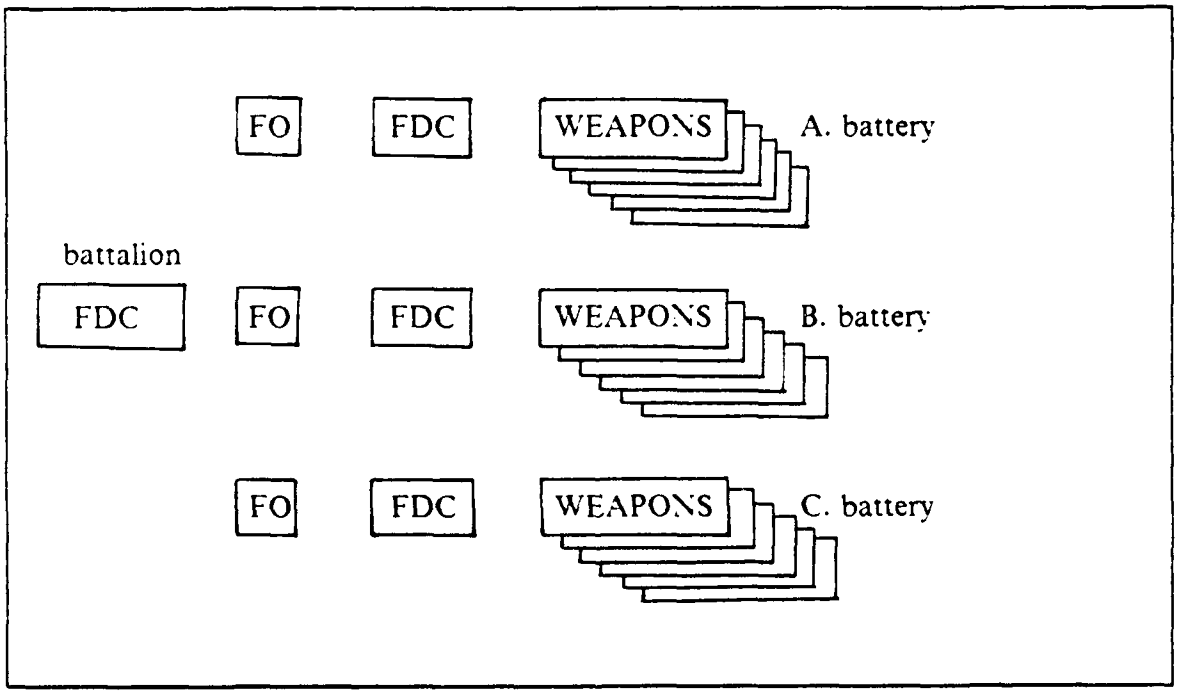


Figure 3. The field artillery battalion fire support system

In order to apply reliability concepts to the fire support system, block diagrams can be constructed according to fire requests.

B. DETAILED BLOCK COMPONENTS

First, the detailed block components need to be explained. Each block consists of several equipments and a crew component as shown in Figure 3 below. The acronym SPP refers to a sound powered phone.

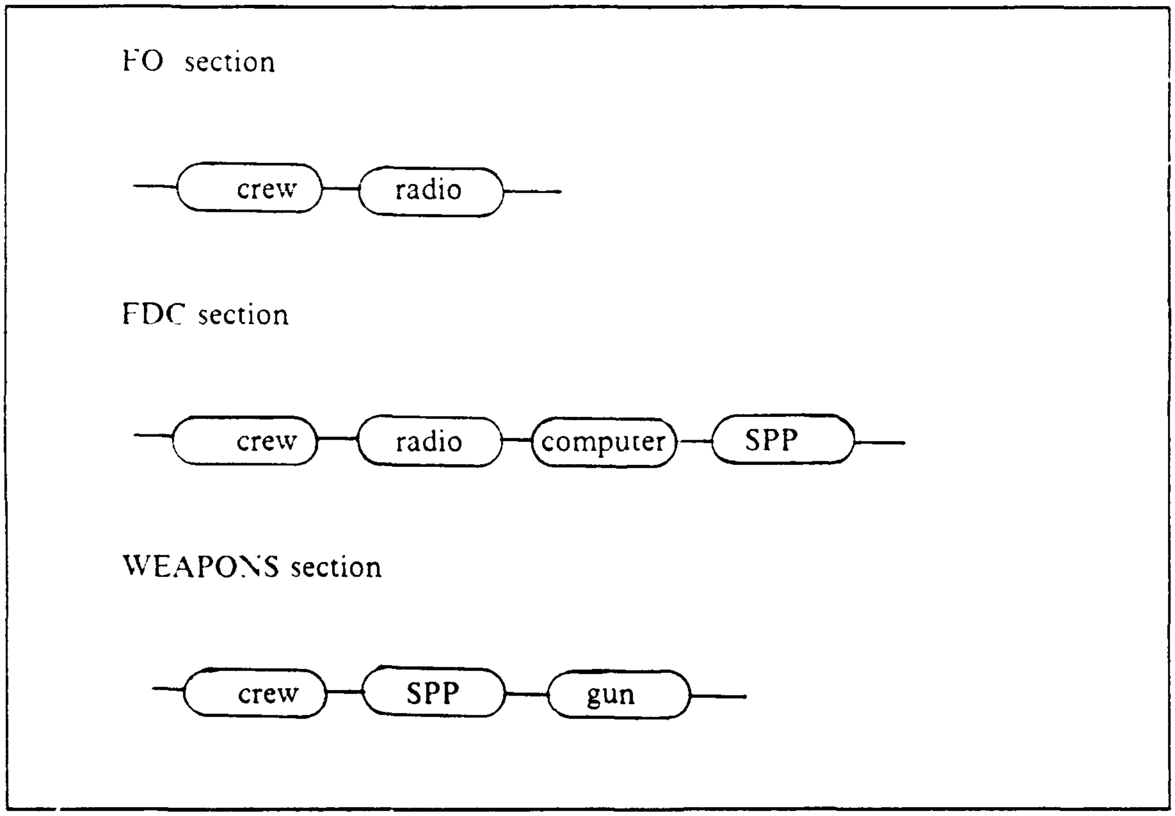


Figure 4. The components of each system block

C. BLOCK DIAGRAMS BASED ON FIRE SUPPORT MISSIONS

The mission of a FAB can be classified as direct support (DS), reinforcing (RF), general support/reinforcing (GSR) and general support (GS) in accordance with the tactical situation [Ref. 3 : pp. 3-8]. The number of fire units which participate in any tactical mission depends on the target size. Thus block diagrams of the FSS differ according to the mission and targets.

1. Small target

Usually fire on a small target is requested by a battery FO when the FAB is assigned a DS tactical mission. Each battery fires separately for each fire request. The block diagram of the fire support system is as shown in Figure 5 below.

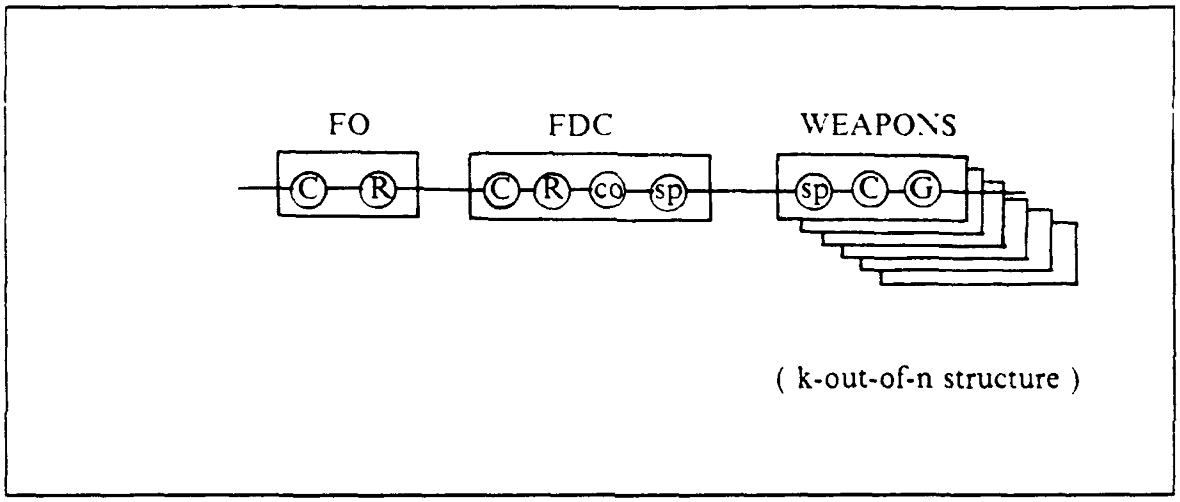


Figure 5. The block diagram of a battery FSS for a small target

Even though each battery operates three or four FO's, only one FO can request a fire mission at a time. Also all guns of the battery are usually fired at the same time, as if they are one gun. So the WEAPONS section is a basic fire unit. But, if we consider partial availability of the weapons, the WEAPONS section can be viewed as a k-out-of-n system. That is, if k or more of the n guns function, that can be considered as a WEAPONS section success. A typical WEAPONS section consists of six guns with crew teams. So, if we assume that 5 or more of 6 guns and their crew teams functioning is a section success, we can consider the WEAPONS block as 5-out-of-6 system.

2. Large/multiple targets

This kind of fire request information usually comes from upper artillery headquarters or the supported unit's Tactical Operation Center (TOC) when the FAB is assigned a GSR or GS tactical mission. The target information may come from the subordinate battery FDC when the FAB has a DS tactical mission and the target characteristics (size, number, etc) exceed the ability of the battery FSS. These fire support missions are usually performed by battalion concentrated fire or fire mission allocation. The battalion FDC controls subordinate batteries simultaneously or separately to supply appropriate fire power according to the tactical situation. So as in Figure 6 , when the battalion FDC controls the batteries, just the crew component and SPP in the battery FDC are needed and the FO is not needed.

In order to suppress a large target, available fire support elements of the FAB participate depending on the target size. Time on target (TOT) or concentrated fire is used. When planned targets are engaged for attack or defense operations, or when the FAB receives a fire request from the supported unit TOC for several small targets, fire mission allocation should be performed. This is the most typical fire support mission for the field artillery battalion. The battalion FDC controls the batteries FDC and WEAPONS. In these cases the available battery FSS's can be viewed as a k-out-of-n system. The number of available battery FSS's is n, and the value of k is decided according to the target size or the number of small targets. When the target size is very big or the number of the requested targets is greater than or equal to the number of available batteries, all FSS's will be used and the resulting n-out-of-n structure reduces to a series system. But, when the number of available FSS's is enough to support the fire requests, k may be smaller than n.

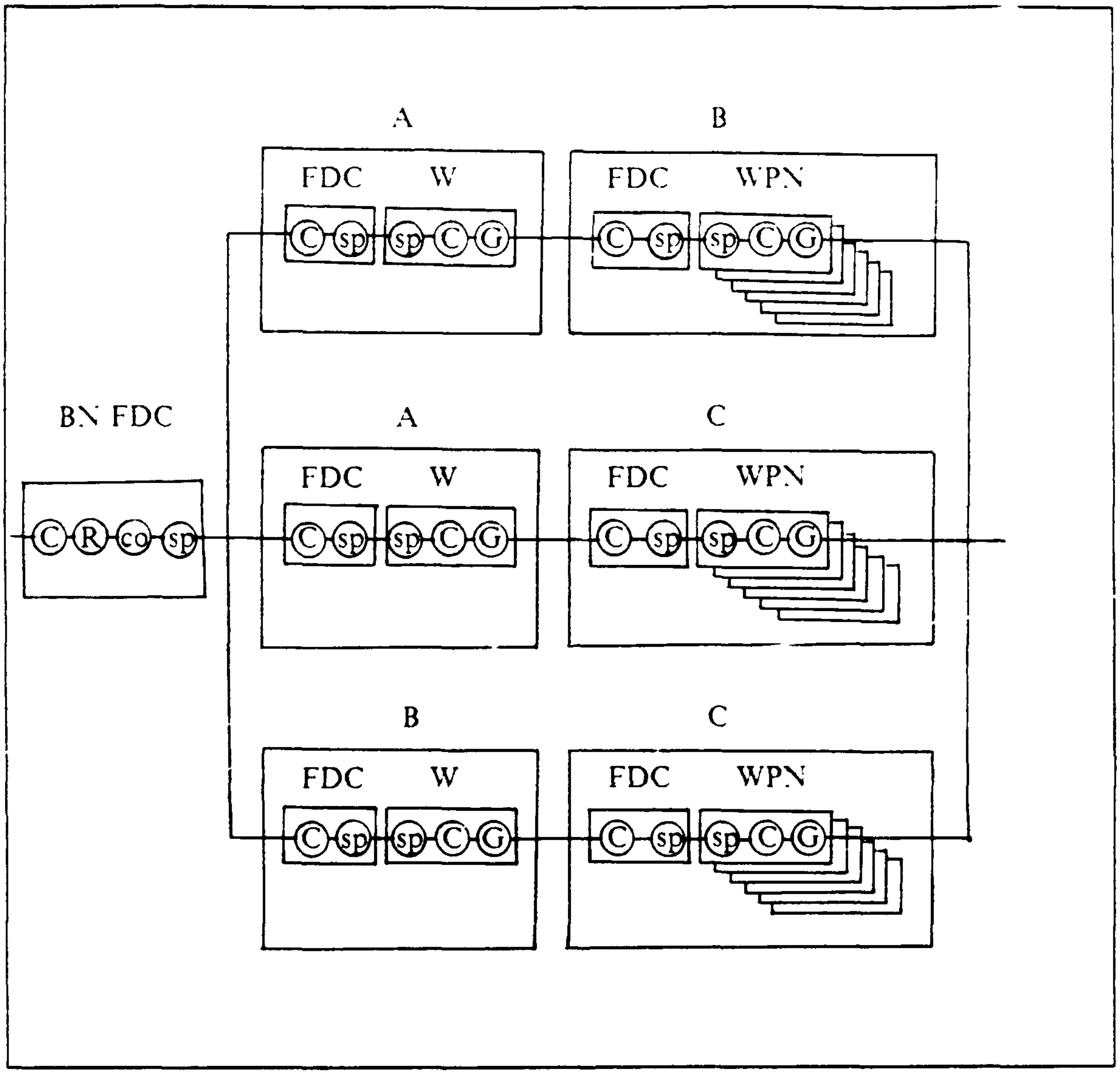


Figure 6. The typical FSS of the FAB (2-out-of-3 system)

In addition, we could consider RF tactical mission situations involving more than one FAB. Then, the number of available batteries is increased. Also the block diagram will be changed depending on the number of targets or target characteristics.

IV. RELIABILITY MODEL

At a particular point in time the fire support system and its sections are required to perform a function for which they are designed. In this chapter, following the block diagrams in Chapter III, fire support system reliability based on the fire support mission will be formulated with the combined reliabilities of the crews and equipments included in that formulation.

A. SYSTEM RELIABILITY BASED ON THE FIRE SUPPORT MISSION

The reliability of the fire support system (FSS) will be considered for two missions. These mission reliabilities will be utilized to analyze the relationship between the training effect and equipment reliability for these selected FSS missions.

1. Battery FSS for small targets

When the tactical mission is direct support (DS), most of the fire will be applied to a small target as requested by the battery FO as shown in Figure 5. In order to derive the system reliability function easily we need to consider the subsystems of the FSS. The subsystems can be the sections of the fire support system composed of each equipment and its crew component. The reliability of a subsystem depends on the equipment reliability and the probability of the crew component functioning.

Let the reliability function of each subsystem be as follows:

The reliability of the FO section is given by

$$P_{FO} = P_{FO,cr} P_{FO,R}$$

where P_{FO} = the reliability of the FO subsystem

$P_{FO,cr}$ = the reliability of the FO's crew component

$P_{FO,R}$ = the reliability of the FO's radio component

The reliability of the FDC section is given by

$$P_{FDC} = P_{FDC,cr} P_{FDC,R} P_{FDC,co} P_{FDC,sp}$$

where P_{FDC} = the reliability of the FDC subsystem

$P_{FDC,cr}$ = the reliability of the FDC's crew component

$P_{FDC,R}$ = the reliability of the FDC's radio component

$P_{FDC,co}$ = the reliability of the FDC's computer component

$P_{FDC,sp}$ = the reliability of the FDC's SPP component

The reliability of each gun section of the WEAPONS section is given by

$$P_G = P_{G,cr} P_{G,sp} P_{gun}$$

where P_G = the reliability of a gun section

$P_{G,cr}$ = the reliabilityof the gun's crew component

$P_{G,sp}$ = the reliability of the gun's SPP component

P_{gun} = the reliability of the cannon component

At this point we need to consider the WEAPONS subsystem reliability when a k-out-of-n system is allowed. If the gun section reliabilities are identical, the number of functioning components will have a binomial distribution with parameters n and p_G. Thus the reliability of the WEAPONS section, P_{WPN} is given by [Ref. 5 : pp. 430]

$$P_{WPN} = \sum_{i=k}^{n} \binom{n}{i} P_G^i (1 - P_G)^{n-i}$$

where n = available gun sections

k = minimum number of guns required to accomplish the mission

Then the reliability function of the total FSS for a small target is given by

$$P = P_{FO}P_{FDC}P_{WPN}$$

2. Battalion FSS for large/multiple targets

The FSS reliability for the typical fire support mission of the field artillery battalion (FAB) involves the reliability of a battalion FDC and the reliabilities of the battalion's batteries used as a k-out-of-n system as shown in Figure 6. When we consider the case that at least two batteries of the three batteries (A, B, C) and the battalion FDC are needed to function, the following reliability is obtained for a 2-out-of-3 battery FSS.

$$P = P_{BF}(P_A P_B + P_A P_C + P_B P_C - 2P_A P_B P_C)$$

where P_{BF} = the probability of the battalion FDC functioning

P_i = the probability of battery i functioning

for i = A, B, C

The components of the battery FSS are different from the small target case since the battery FO is not needed for the fire support mission. That is, the reliability of the modified battery FSS is given by

$$P_i = (P_{i,FDC,cr}P_{i,FDC,sp})P_{i,WPN}$$

where $P_{i,FDC,j}$ = the probability of mission success of a component j in battery i FDC

for i = A, B, C, and j = crew, SPP

$P_{i,WPN}$ = the probability of mission success of WEAPONS section in battery i

for i = A, B, C

Thus, the total system reliability function for large multiple targets is given by

$$P = P_{BF}(P_A P_B + P_A P_C + P_B P_C - 2P_A P_B P_C)$$

$$= P_{BF}[(P_{A,FDC,cr} P_{A,FDC,sp} P_{A,WPN})(P_{B,FDC,cr} P_{B,FDC,sp} P_{B,wpn})$$

$$+ (P_{A,FDC,cr} P_{A,FDC,cr} P_{A,WPN})(P_{C,FDC,cr} P_{C,FDC,sp} P_{C,WPN})$$

$$+ (P_{B,FDC,cr} P_{B,FDC,sp} P_{B,WPN})(P_{C,FDC,cr} P_{C,FDC,sp} P_{C,WPN})$$

$$- 2(P_{A,FDC,cr} P_{A,FDC,sp} P_{A,WPN})(P_{B,FDC,cr} P_{B,FDC,sp} P_{B,WPN})(P_{C,FDC,cr} P_{C,FDC,sp} P_{C,WPN})]$$

B. COMPONENT RELIABILITIES

1. Crew

The reliability of a crew as a component acting in series with an equipment can be predicted from the current training level of the crew. Each commander evaluates the current training level of his crews from an annual combat readiness inspection. The level of crew training is expressed by the score which the crew receives in the combat ability inspection. The combat ability inspection for the crew team is a MOS (military occupational specialty) test related directly to the task of the crew in the actual operational situation. The MOS test consists of an actual performance test rather than a written test. The examiners check whether the crew team can accomplish its mission under an imaginary situation similar to an actual operation.

An ideal proficiency test for a crew would be based on repeated trials of the crew's operational task under realistic operational conditions. The number of trials would be sufficiently large for the observed percentage of successful executions of the task to represent the probability that the task would be successfully performed in actual service If the score on such a test is the observed percentage of successes, this would lead to the relationship, $P(s) = \frac{s}{100}$ between the score s on the test and probability of success $P(s)$ in actual service. Feasible proficiency tests fall short of the ideal in at least two respects, the difficulties in simulating the operational task and the operational conditions and the economics of conducting a large number of trials. However, the tests that are used are scored on a scale of 0 % to 100 %.

There exists a criterion value of the score for MOS (military occupational specialty) certification. This is a qualification standard to judge whether a crew or a crew team has an acceptable probability of accomplishing its mission or not. A major feature of actual proficiency tests is the determination of the criterion score which is used to classify crews as qualified for duty or unqualified. Belief that actual tests are derived from substantial expertise and experience, coupled to the importance of the criterion score cr, serves to support the assumption that $P(cr) = \frac{cr}{100}$.

Usually, the military commander would like to avoid risk in evaluating his unit's combat power for the real situation. But the commander can not consider that if the test score is low or zero, the crew team doesn't have any ability. Thus, the commander judges that when the score is greater than or equal to the criterion, the linear formula $P(s) = \frac{s}{100}$ overstates the crew reliability, and when the score is less than the criterion, it understates. From that point of view, we redefine $P(s)$. For $0 \leq s \leq 100$ assume that

$$P(s) - P(cr) = f(s)[\frac{s}{100} - \frac{cr}{100}]$$

where $f(s)$ is some function of s such that $0 \leq f(s) \leq 1$.

Since $P(cr) = \frac{cr}{100}$, this can be rewritten as

$$P(s) - P(cr) = f(s)[\frac{s}{100} - P(cr)] \qquad (4.1)$$

First of all, let $f(s)$ be a positive constant c less than or equal to 1. Then from equation (4.1) above,

$$P(s) - P(cr) = c[\frac{s}{100} - P(cr)]$$

$$P(s) = (1 - c)P(cr) + c\frac{s}{100}$$

$$= \frac{c}{100}s + (1 - c)\frac{cr}{100} \qquad (4.2)$$

For example, if c = 1, then $P(s) = \frac{s}{100}$, as would be the case for an ideal test. The determination of the constant value c would require knowledge of $P(s)$ for at least one value of s other than cr. This formula has the property that $P(s)$ is increasing for $0 \leq s \leq 100$. Next let $f(s) = P(s)$. Then from equation (4.1)

$$P(s) - P(cr) = P(s)[\frac{s}{100} - P(cr)]$$

$$P(s) = \frac{P(cr)}{P(cr) + (1 - s/100)}$$

$$= \frac{cr/100}{cr/100 + (1 - s/100)}$$

$$= \frac{cr}{cr + (100 - s)} \qquad (4.3)$$

This function is reasonable for the general relationship bewteen the score and the reliability in the whole score range, $0 \leq s \leq 100$. This formula also has the property that $P(s)$ is monotone increasing for $0 \leq s \leq 100$ in a given interval. Also $f(s)$ can be considered as a linear function of s, $f(s) = \frac{s}{100}$. Applying this to equation (4.1), the following formula is obtained.

$$P(s) - P(cr) = \frac{s}{100}\left[\frac{s}{100} - P(cr)\right]$$

$$P(s) = \frac{s}{100}\frac{s}{100} + \left(1 - \frac{s}{100}\right)P(cr)$$

$$= \frac{1}{100}\left[\frac{1}{100}s^2 - \frac{cr}{100}s + cr\right] \qquad (4.4)$$

This kind of function is reasonable for a limited score range, $cr \leq s \leq 100$, but $P(s)$ is not increasing in the interval $0 \leq s \leq cr$. These relationships are shown in Figure 7 below.

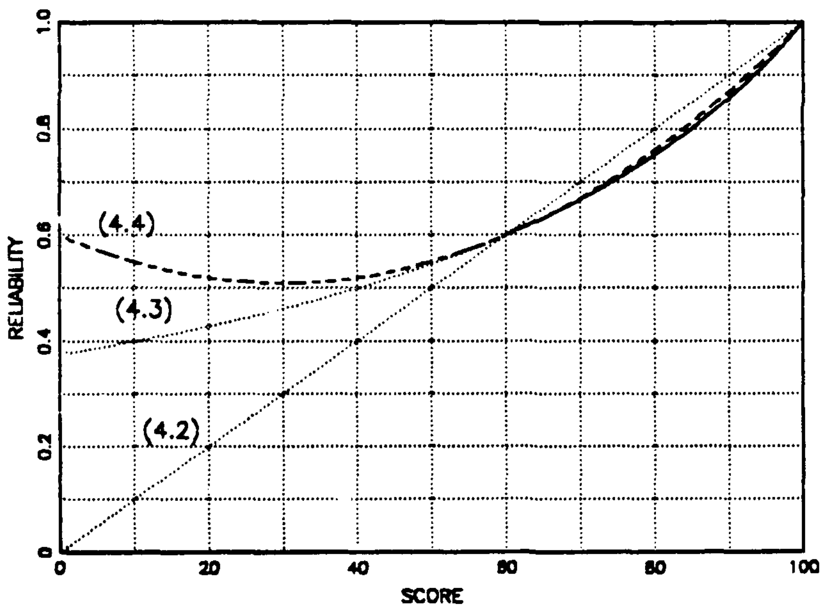


Figure 7. **The crew reliability functions (at cr = 60)**

In the real situation when the inspection score is less than the criterion value, the commander usually requires more training and exercise for the crew instead of giving any missicn. The reliability of a crew receiving a score less than a criterion can be ignored in the FSS reliability analysis. Thus a modification of formula (4.4) which sets $P(s) = 0 \;\; for \; 0 \leq s \leq cr$ can be allowed.

As shown in Figure 7 as long as only scores which are greater than the criterion are considered by the commander, several kinds of functions are available for the crew reliability depending on the choise of $f(s)$. Also, since the final result frequently depends on the commander's experience and his self-confidence, the formula for crew reliability is somewhat flexible. The first linear function (4.2) where c = 1 can be considered as a upper limit of crew reliability in the limited score range, $cr \leq s \leq 100$. It is desirable to select formula (4.3) as a basis for the crew reliability function since it seems reasonable for the general idea of the relationship between score and reliability over the whole score range. So the crew reliability function that will be used here is

$$P(s) = \begin{cases} \dfrac{cr}{cr + (100 - s)} & \text{if} \quad cr \leq s \leq 100 \\ \\ 0 & \text{otherwise} \end{cases}$$

2. Equipment

The reliability of the equipment component can be conjectured directly by field experience based on the equipment state. Usually modernized military equipments have good quality and high reliability, especially the computer. The SPP and radio are kept in good condition by battalion maintenance. Gun reliability is affected by age since it is difficult to repair structural damage from use. Also, accuracy is decreased by age.

So the field artillery battalion classifies its guns by their muzzle state or age as measured by the number of fired rounds. Guns which have approximately the same condition are assigned to a battery. Thus the gun reliability will be different for each battery and can be obtained from the age and muzzle state of its guns.

V. IMPLEMENTATION AND ANALYSIS

A. IMPLEMENTATION OF THE FSS MODEL

1. Computer language and covered cases

The programming language used to run the FSS reliability model is FORTRAN on an IBM 3033. As shown in the block diagrams before, two kinds of the FSS missions are considered, an independent battery FSS for small targets during a DS tactical mission and a typical battalion FSS for a large/multiple targets.

2. Input data

The main issue is to analyze the crew training effect on FSS reliability. The inputs for equipment reliability are hypothesized from military experience with field artillery. The training level inputs come from our model of combat ability inspection. Also, it will be assumed that five or more gun sections of a WEAPONS subsystem and two or more batteries of the battalion FSS need to function.

a. Equipment reliability data

Firing equipments have high reliability. The computer is almost perfect and some other equipments are very reliable as long as they are not too old. Also most military equipments have approximately similar frequency of use in peace time because they are controlled by the regular training and exercise planning of the army headquarters. Even if the SPP or radio is somewhat old, its reliability will be high through battalion maintenance. Generally we can consider that identical equipments have approximately the same probability of perfomance. Gun reliabilities will be somewhat different for each battery since gun reliability is affected by historical frequency of use. Guns are assigned to batteries according to age and state of the gun to increase consistency in hitting the target when applying corrections to battery fire data. A gun's age is determined by the number of fired rounds. Suppose that battery gun condition corresponds to the order A, B, C of the batteries. Then the equipment reliabilities could be as shown in Table 1 below.

Table 1. RELIABILITIES FOR EACH KIND OF EQUIPMENT

equipmment	computer	radio	SPP	guns		
				A	B	C
reliability	0.9999	0.99	0.99	0.99	0.97	0.95

b. Crew score

The result of the annual combat ability inspection for each crew section of the FSS provides the input for crew training level. Suppose that the result of the inspection is as in Table 2 below.

Table 2. CREW TEAM TRAINING LEVELS EXPRESSED BY SCORE

section	A	B	C	BN	average
FO	90	95	85	-	90
FDC	85	90	90	95	90
GUN	90	90	85	-	86.7

These scores can be translated to crew component reliability by using the crew reliability function formulated in Chapter IV.

c. *FSS reliabilities*

The FSS reliabilities are obtained by running the FSSR FORTRAN program in Appendix B with the equipment reliabilities and crew scores assumed above. The battery FSS reliabilities for small targets are shown in Table 3.

Table 3. BATTERY FSS RELIABILITIES

battery	A	B	C	BN(average)
reliability	0.501	0.547	0.359	0.469

Also the reliability for the typical FSS of the FAB shown in Figure 6 in Chapter 3. can be computed from the FSSR program. For the current inputs the FSS reliability is shown in aTable 4 below.

Table 4. THE RELIABILITY OF A TYPICAL FAB FSS

system	BN FDC	2-out-of-3 sub system				total FSS
		A	B	C	sys-tem	
reliability	0.905	0.596	0.604	0.458	0.580	0.525

From the two tables above the FSS reliability of the FAB is approximately 50 % in two typical missions. The decision maker requires more information to decide policy effectively. So we need to consider the relative FSS reliabilities for different training levels and different equipment conditions.

B. CREW TRAINING AND EQUIPMENT RELIABILITY EFFECT

In this section the general effect of crew training and equipment reliability on FSS reliability will be analyzed. Average values of crew scores and equipment reliabilities can be used to represent the overall crew training level and overall equipment condition.

After analyzing the separate effects of crew and equipment on FSS reliability, their combined effect will be considered.

1. Crew training effect on FSS reliability

In order to evalute the effect of training on FSS reliability assume that all equipments are perfect. Then the following graph represents the effect of crew average score on FSS reliability.

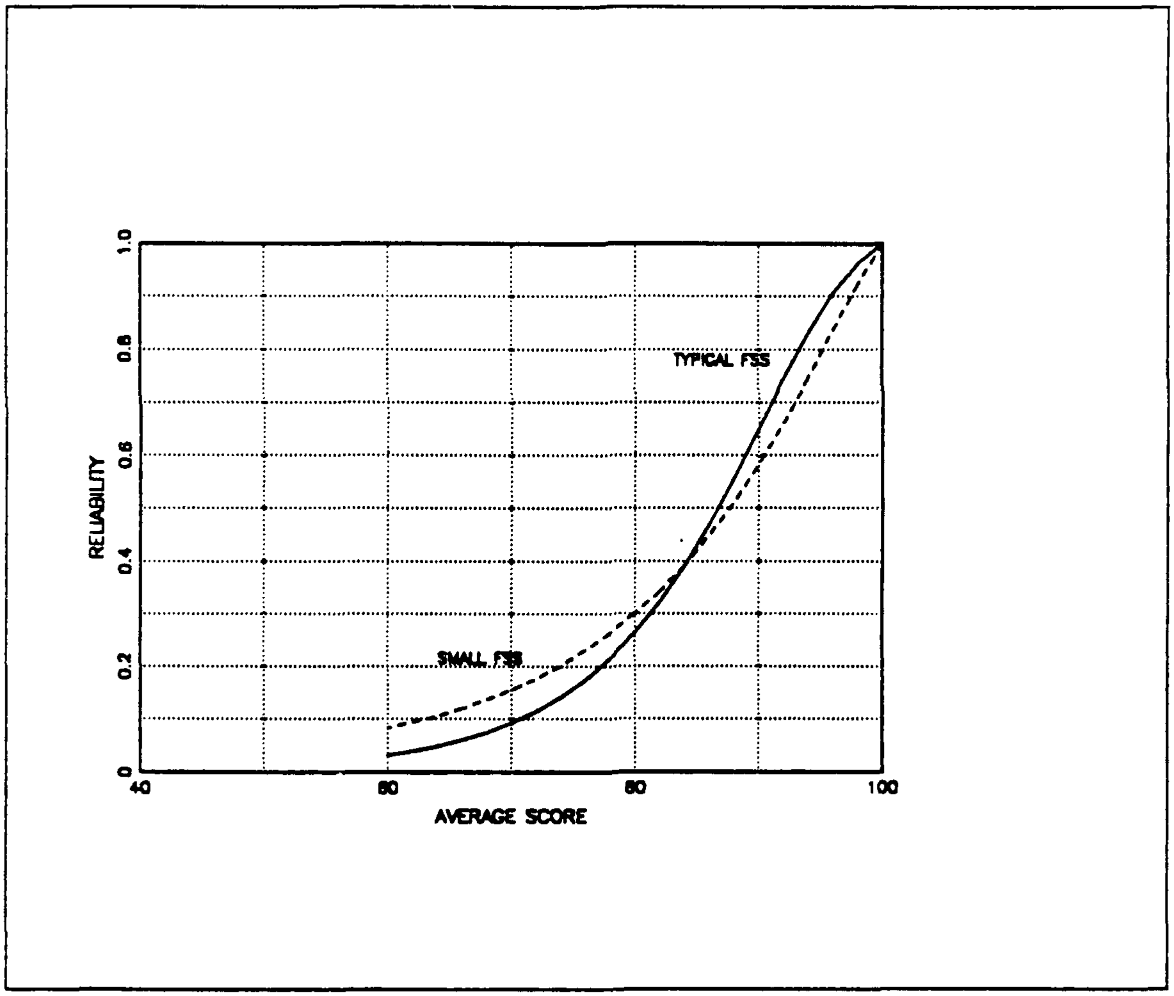


Figure 8. Crew average score effect on FSS reliability when equipments are perfect.

As shown in Figure 8, FSS reliability is very sensitive to crew average score in the high score range. The effect of crew score on a battery (small) FSS reliability is pronounced for scores greater than 80. The effect on the reliability of a battalion (typical) FSS is pronounced between 80 and 95.

2. Equipments effect on FSS reliability

In order to evalute the effect of equipment on FSS reliability assume that all crews are perfect. Then the following graph represents the effect of equipment condition on FSS reliability.

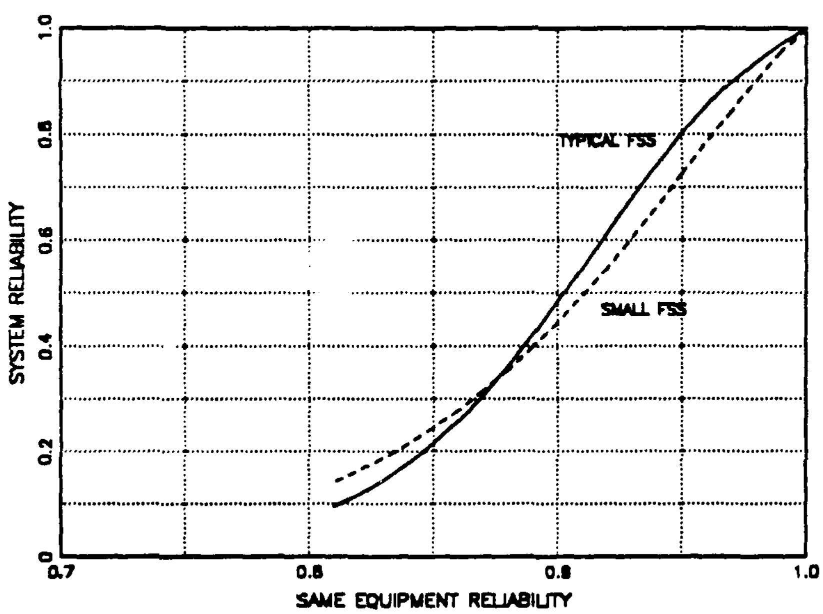


Figure 9. Pure equipment effect for the FSS reliability when ·w components are perfect.

As shown in Figure 9, FSS reliability is also sensitive to total equipment condition for high equipment reliabilities. The equipment effect on a battery (small) FSS reliability is pronounced for reliability values greater than 0.87. The effect on the reliability of a battalion (typical) FSS is pronounced between 0.85 and 0.97.

3. Mixed effect of crew and equipment on FSS reliability

Figure 10 and Figure 11 show three dimensional graphs of FSS reliability, crew score and equipment condition for each target type.

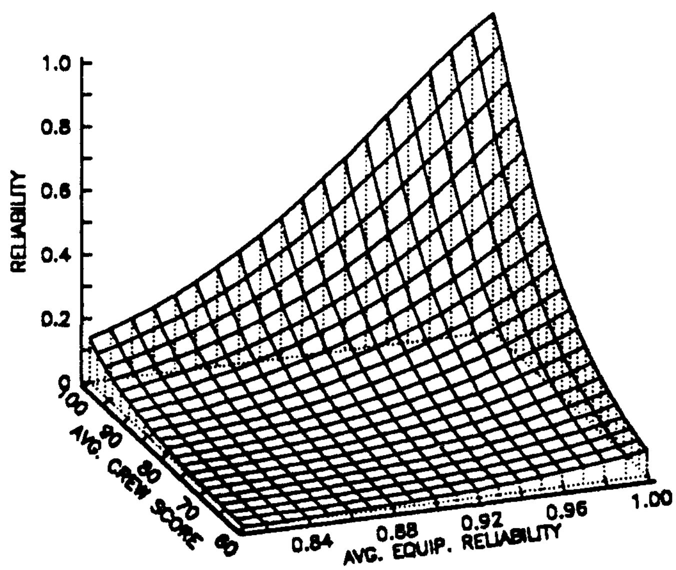


Figure 10. Mixed effect of crew and equipment on small FSS reliability

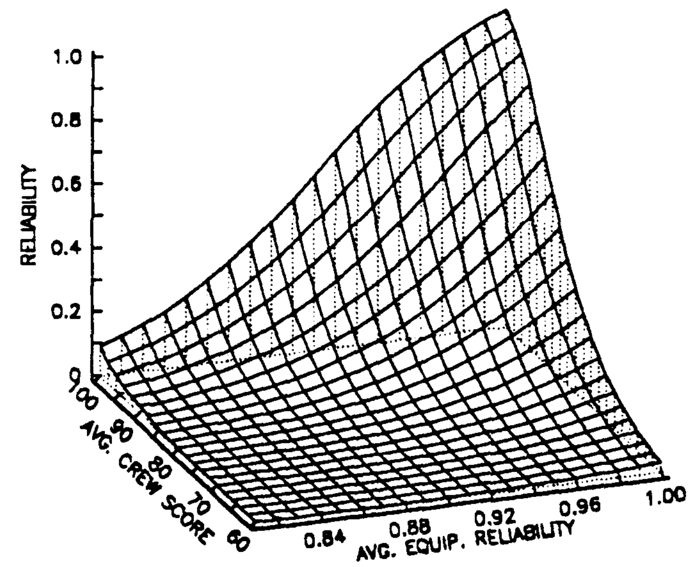


Figure 11. Mixed effect of crew and equipment on typical FSS reliability

As shown in the graphs, the mixed effects of crew score and equipment reliability on both systems are pronounced for high scores and reliabilities and they have an approximately similar pattern for the other scores and reliabilities. If either crew score or equipment reliability is very good, some trivial defect of the other can be compensated. But when either crew score or equipment reliability is too low, FSS reliability is seriously degraded. Thus balance at a high level is best for FSS reliability. Next we need to consider the effect of crew score within each section to investigate FSS reliability in detail.

C. CREW SCORE EFFECT ON FSS RELIABILITY BY CREW TYPE

The analysis of component reliabilities and crew training levels within various sections gives a refined persective to the decision maker.

1. Battery FSS for small targets

In order to evalute the training effect for each crew type (FO, FDC ,GUN) assume that all equipments and other crew types are perfect. Then the following graph represents the relationship between battery FSS reliability and the training level of each crew type.

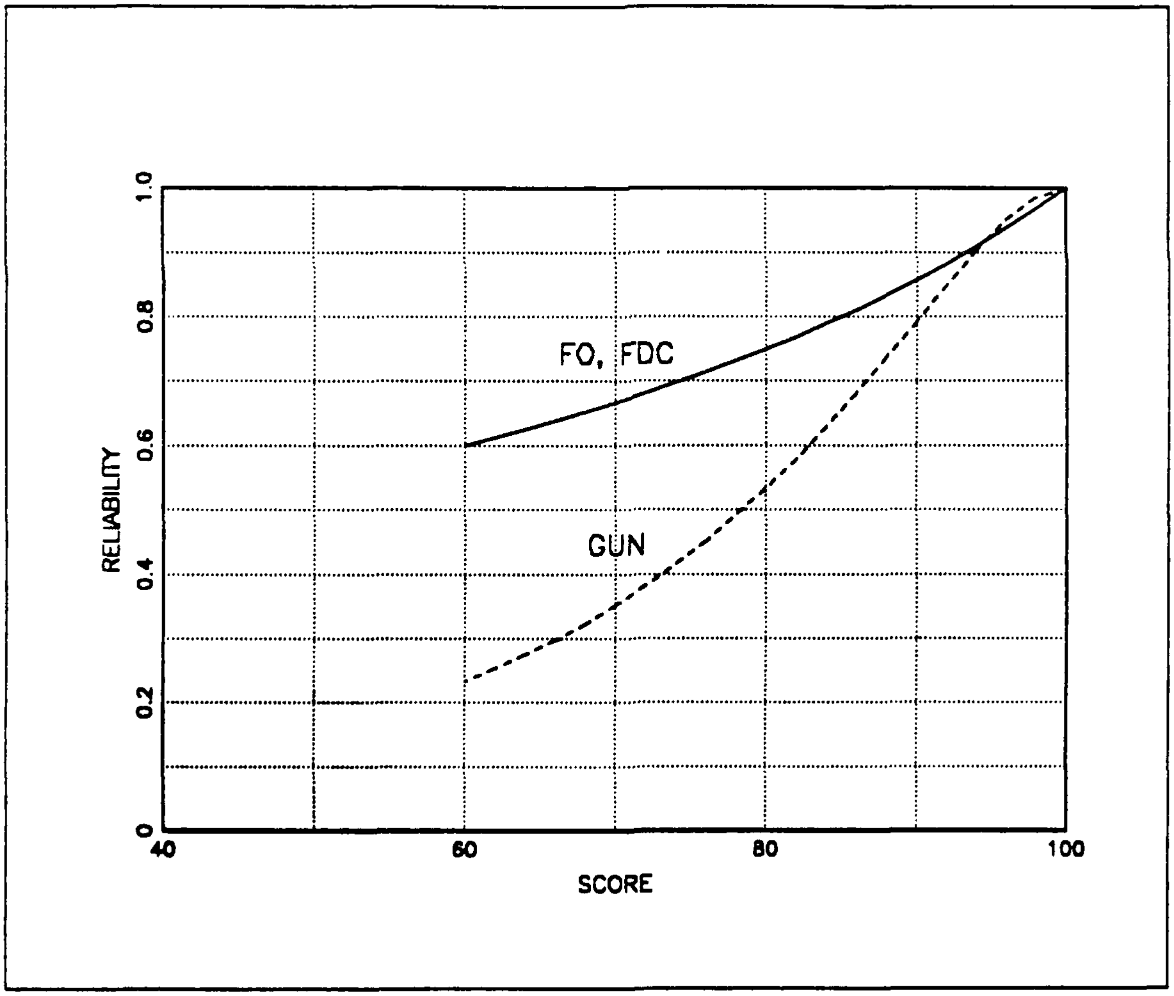


Figure 12. Crew effect on small FSS reliability by sections

In the graph above the GUN crew graph represents the combined effect of several gun crews with identical gun conditions in a 5-out-of-6 WEAPON subsystem. The data comes from Appendix D. As seen in Figure 12, FO and FDC crew types have the same effect since the FO or FDC crews act in series with the remainder of the system. Since gun crews are components of gun sections in a 5-out-of-6 subsystem, their training effect on the total system reliability is different. From the graph it appears that the GUN crew effect is pronounced in the score range between 75 % and 95 %. So GUN crews need a high training level to contribute effectively to system reliability for small targets. In fact, GUN crew ability is the most important element of a battery FSS.

2. Battalion FSS for large/multiple targets

In this system as long as two batteries and the battalion FDC are perfectly functioning, components of the other battery don't effect the total system reliability. Only the battalion FDC crew affects the system reliability. The battalion FDC effect is the same as the battery FDC effect.

D. COST EFFECTIVENESS OF CREW TRAINING

Obtaining the most cost effective result is an admirable goal, whatever that may mean [Ref. 6: pp. 29]. Maximizing reliability within budget limits or minimizing cost to achieve a reliability goal is the main issue for the decision maker. But it is not easy to judge cost effectiveness of crew training against equipment condition. There exists much uncertainty in measuring the cost to accomplish a required training level. Training costs include not only direct costs such as books, aids, instructors and supplies but also indirect costs of training [Ref. 7: pp. 17]. These costs are related to the lost productivity of personnel during training. Costs for MOS training are related to many unit conditions such as morale, welfare, supply, and non MOS basic training.

However FSS reliability can be used as a kind of measure of effectiveness (MOE). This MOE evaluates aspects of performance relevant to operational issues and provides a basis for decision making. By analyzing FSS reliability in a given situation and avoiding extremely bad combinations of training and equipment, an alternative to cost effectiveness analysis can be accomplished. In this way the decision maker can implement the general training concept for a field artillery battalion (FAB), which is that a commander selects appropriate training objectives by analyzing his unit's strengths, weaknesses and resources, and then sets priorities for training to get the most from limited resources [Ref. 3: pp. 2-2]. An analyst can recommend the general approach to using the FSS reliability model. When a major defect in FSS reliability is derived from the model due to poor equipment, equipment condition must be improved to avoid intensive training needed to compensate for the defect. In the example considered in Section V-1, intensive crew training is needed since the maintenance ability of a FAB results in high levels of equipment reliability.

VI. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

The focus of this thesis was on modeling the effect of training on crew performance and then evaluating the impact of training on battalion fire support system (FSS) reliability. In order to incorporate the effect of crew training into FSS reliability, a crew reliability function was derived from military expertise and common ideas about the results of combat ability inspections. Then formulating an overall system reliability model for the typical fire support missions of a field artillery battalion (FAB) permits analyzing the effect of crew training on FSS reliability.

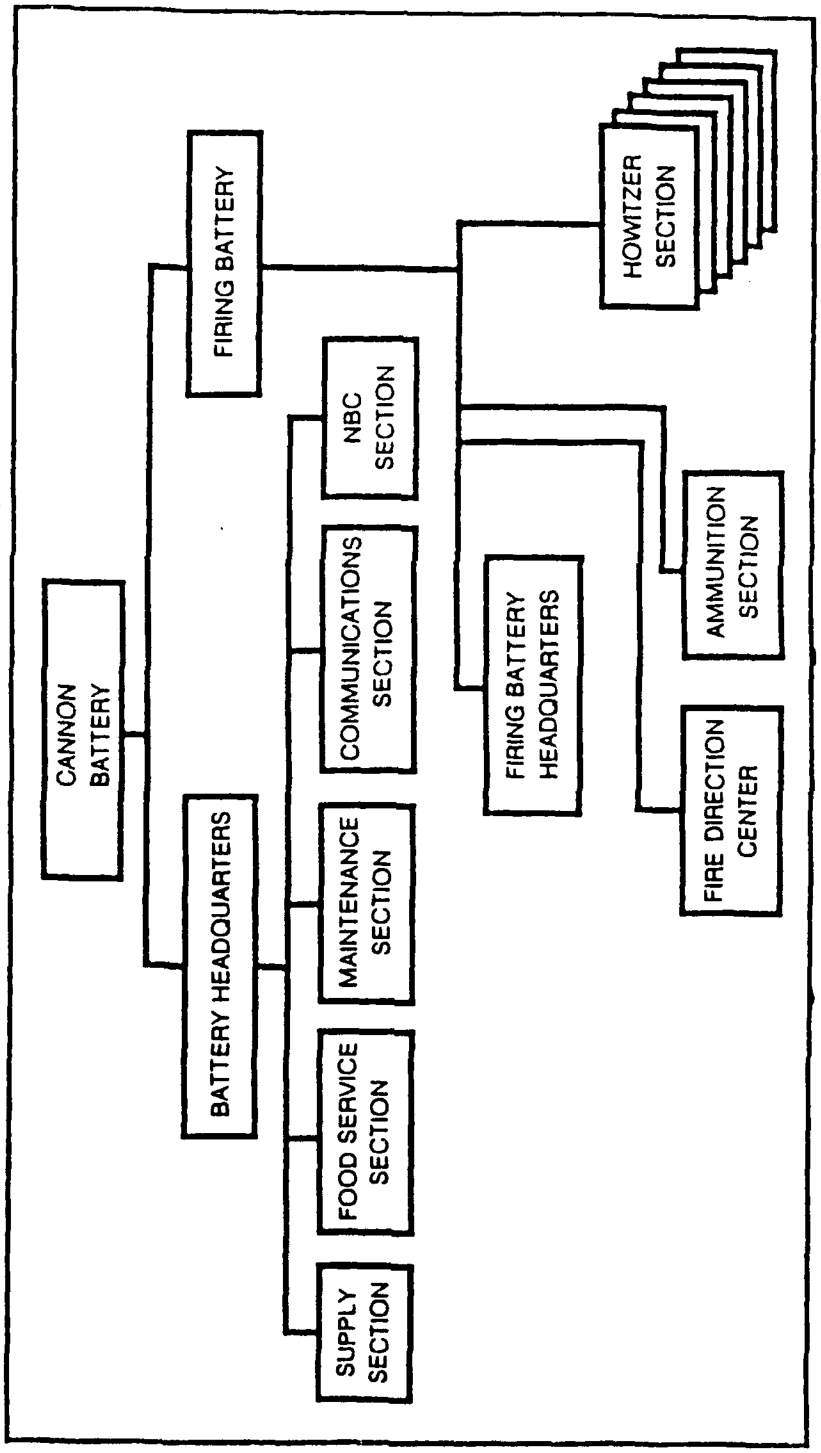
The typical FAB achieves high equipment reliability by its maintenance ability. As long as the equipment reliabilities are very high, the crew training effect on FSS reliability is pronounced for high scores. Thus the maintenance of crew scores and equipment reliabilities at high levels is important to overall FSS reliability. In the example considered in Section 5.1 crew training level is required to be stable at a high score, at least 90 %.

When crews are well trained and the FSS reliability of a FAB is high, it will contribute effectively to today's battlefield requirements on a combined arms team. This model gives a reasonable analysis of the FSS reliability of a FAB. The decision maker can use it as a reference to evaluate combat ability.

B. RECOMMENDATIONS

A similar procedure to the battalion FSS reliability analysis can be applied to other field artillery echelons by constructing different block diagrams from additional scenarios. One focus of future research should be the MOS check list and criterion standard.

APPENDIX A. FA BATTALION CANNON BATTERY ORGANIZATION



APPENDIX B. FORTRAN PROGRAM FOR FSS RELIABILITY

```
C  ****************************************************************************
C  *                                                                          *
        PROGRAM FSSR
C  *                                                                          *
C  ****************************************************************************
C  *                                                                          *
C  *  THIS IS A PROGRAM TO COMPUTE THE FIRE SUPPORT SYSTEM                    *
C  *  RELIABILITY FOR A GIVEN CONDITION.  EACH RELIABILITY                    *
C  *  OF TWO SPECIFIC FSS IS OBTAINED BY CONTROLLED INPUT DATA.               *
C  *                                                                          *
C  *  THIS PROGRAM CONTAINS FOLLOWING MODULES                                 *
C  *    - MAIN PROGRAM                                                        *
C  *    - FO                                                                  *
C  *    - FDC                                                                 *
C  *    - GUN                                                                 *
C  *    - WEAPON                                                              *
C  *    - MFDC                                                                *
C  *    - CREW                                                                *
C  *                                                                          *
C  *  USED VARIABLES                                                          *
C  *    TARGET : FIRE SUPPORT MISSION ID ('LARGE' OR 'SMALL')                 *
C  *    CRT : CRITERION (%) OF CREW TRAINING LEVEL TEST                       *
C  *    P : OVERALL FSS RELIABILITY                                           *
C  *    PB(I) : THE RELIABILITY OF BATTERY I SUBSYSTEM IN TYPICAL FSS         *
C  *    FOS : FO CREW SCORE                                                   *
C  *    PFOR : FO RADIO RELIABILITY                                           *
C  *    FDCS : FDC CREW SCORE                                                 *
C  *    PFDCR : FDC RADIO RELIABILITY                                         *
C  *    PFCOM : FDC COMPUTER RELIABILITY                                      *
C  *    PFSPP : FDC SPP RELIABILITY                                           *
C  *    GS : GUN SECTION CREW SCORE                                           *
C  *    PGSPP : GUN SECTION SPP RELIABILITY                                   *
C  *    PG : GUN RELIABILITY                                                  *
C  *    PFO : THE RELIABILITY OF FO SECTION SUBSYSTEM                         *
C  *    PFDC : THE RELIABILITY OF FDC SECTION SUBSYSTEM                       *
C  *    PGUN : THE RELIABILITY OF GUN SECTION SUBSYSTEM                       *
C  *    PWPN : THE RELIABILITY OF WEAPONS SUBSYSTEM CONSISTS OF N GUNS        *
C  *    BNFS : BATTALION FDC CREW SCORE                                       *
C  *    BNFR : BATTALION FDC RADIO RELIABILITY                                *
C  *    BNFCOM : BATTALION FDC COMPUTER RELIABILITY                           *
C  *    BNFSPP : BATTALION FDC SPP RELIABILITY                                *
C  *    MFS : BATTERY FDC CREW SCORE FOR THE MODIFIED FSS                     *
C  *    MFSPP : BATTERY FDC SPP RELIABILITY FOR THE MODIFIED FSS              *
C  *    MGS : GUN SECTION CREW SCORE FOR THE MODIFIED FSS                     *
C  *    PMGSPP : GUN SECTION SPP RELIABILITY FOR THE MODIFIED FSS             *
C  *    MGUN : GUN RELIABILITY FOR THE MODIFIED FSS                           *
C  *    PMFDC : FDC RELIABILITY IN THE MODIFIED FSS                           *
C  *    PGUN : GUN SECTION RELIABILITY IN THE MODIFIED FSS                    *
```

```
C  *    PMWPN : THE RELIABILITY OF THE MODIFIED WEAPONS SUBSYSTEM       *
C  *    PBN : FSS RELIABILITY FOR SMALL TARGET (AVERAGE VALUE)          *
C  *                                                                     *
C  *********************************************************************
C
C
      REAL CRT,P,PB(10),P23,FOS,PFOR,FDCS,PFDCR,PFCOM,PFSPP,
     +     GS,PGSPP,PG,PFO,PFDC,PGUN,PWPN, PSUM,PBN,
     +     BNFS,BNFR,BNFCOM,BNFSPP,PBNFDC,
     +     MFS,MFSPP,MGS,MGUN,PMFDC,PMGSPP,PMGUN,PMWPN
      INTEGER I,N,K
      CHARACTER*5 TARGET
C
      CALL EXCMS('FILEDEF 01 DISK INPUT0 DATA A1')
      CALL EXCMS('FILEDEF 10 DISK INPUT1 DATA A1')
      CALL EXCMS('FILEDEF 11 DISK INPUT2 DATA A1')
      CALL EXCMS('FILEDEF 02 DISK R OUTPUT A1 ')
C
      DATA PB/10*0.0/
C
C  READ THE MISSION ID(TARGET), CRITERION SCORE(CRT), THE NUMBER OF
C  GUNS IN A BATTERY(N) AND NUMBER OF GUNS FOR FIRE FOR EFFECT(FEE)
C
      READ(1,*) TARGET
      READ(1,*) CRT,N,K
      WRITE(2,*) 'A BATTALION FIRE SUPPORT SYSTEM RELIABILITY'
      WRITE(2,*)
C
C  CLASSIFY THE FIRE SUPPORT SYSTEM TO BE APPLIED ACCORDING TO
C  MISSION ID (TARGET)
C
      IF(TARGET .EQ. 'SMALL') THEN
         PSUM = 0.0
C
C  COMPUTE THE FIRE SUPPORT SYSTEM RELIABILITY FOR EACH BATTERY
C
         DO 11 I = 1,3
              READ(10,*) FOS,PFOR,FDCS,PFDCR,PFCOM,PFSPP,
     +                   GS,PGSPP,PG
C
              CALL FO (CRT,FOS,PFOR,PFO)
C
              CALL FDC (CRT,FDCS,PFDCR,PFCOM,PFSPP,PFDC)
C
              CALL GUN (CRT,GS,PGSPP,PG,PGUN)
C
              CALL WEAPON (N,K,PGUN,PWPN)
C
              P = PFO * PFDC * PWPN
C
              PSUM = PSUM + P
C
              WRITE(2,*) 'BATTERY',I, '       ', P
C
 11      CONTINUE
C
```

```
         PBN = PSUM / REAL(I-1)
         WRITE(2,*)
         WRITE(2,*) 'BATTALION (AVERAGE)','          ', PBN
C
      ELSE
C
C  COMPUTE THE TYPICAL FIRE SUPPORT SYSTEM RELIABILITY OF A FIELD
C  ARTILLERY BATTALION
C
         READ(11,*)  BNFS,BNFR,BNFCOM,BNFSPP
C
         CALL FDC (CRT,BNFS,BNFR,BNFCOM,BNFSPP,PBNFDC)
C
         DO 1 I = 1,3
              READ(11,*) MFS,MFSPP,MGS,PMGSPP,MGUN
C
              CALL MFDC (CRT,MFS,MFSPP,PMFDC)
C
              CALL GUN (CRT,MGS,PMGSPP,MGUN,PMGUN)
C
              CALL WEAPON (N,K,PMGUN,PMWPN)
C
              PB(I) = PMFDC * PMWPN
              WRITE(2,*) 'BATTERY',I, '      ', PB(I)
C
    1    CONTINUE
C
C  COMPUTE THE RELIABILITY OF THE 2-OUT-OF-3 MODIFIED BATTERY (P23)
C
         P23 = PB(1)*PB(2) + PB(1)*PB(3) + PB(2)*PB(3)
     +          - 2*PB(1)*PB(2)*PB(3)
C
C  COMPUTE OVERALL FIRE SUPPORT SYSTEM RELIABILITY OF A FAB
C
         P = PBNFDC * P23
         WRITE(2,*)
         WRITE(2,*) 'TYPICAL BATTALION FSS    ',P
      END IF
C
      STOP
      END
C
C
C  ***********************************************************************
C  *                                                                     *
      SUBROUTINE FO (CRT,FOS,PFOR,PFO)
C  *                                                                     *
C  *  THIS IS A SUBROUTINE PROGRAM TO COMPUTE THE RELIABILITY OF A       *
C  *  FORWARD OBSERVER SUBSYSTEM FOR THE SMALL TARGET FIRE MISSION.      *
C  *                                                                     *
C  ***********************************************************************
C
      REAL FOS,PFOR,PFOCR,PFO,CRT
C
      CALL CREW (CRT,FOS,PFOCR)
C
```

```
      PFO = PFOR * PFOCR
C
      RETURN
      END
C
C
C    ************************************************************************
C    *                                                                      *
      SUBROUTINE FDC (CRT,FDCS,PFDCR,PFCOM,PFSPP,PFDC)
C    *                                                                      *
C    *  THIS IS A SUBROUTINE PROGRAM TO COMPUTE THE RELIABILITY OF A        *
C    *  FIRE DIRECTION CENTER SUBSYSTEM FOR THE SMALL TARGET MISSION.       *
C    *                                                                      *
C    ************************************************************************
C
      REAL CRT,FDCS,PFDCR,PFCOM,PFSPP,PFCR,PFDC
C
      CALL CREW (CRT,FDCS,PFCR)
C
      PFDC = PFCR * PFDCR * PFCOM * PFSPP
C
      RETURN
      END
C
C
C    ************************************************************************
C    *                                                                      *
      SUBROUTINE GUN (CRT,GS,PGSPP,PG,PGUN)
C    *                                                                      *
C    *  THIS IS A SUBROUTINE PROGRAM TO COMPUTE THE RELIABILITY OF A        *
C    *  GUN SECTION SUBSYSTEM.                                              *
C    *                                                                      *
C    ************************************************************************
C
      REAL GS,PGSPP,PG,PGUN,PGCR,CRT
C
      CALL CREW (CRT,GS,PGCR)
C
      PGUN = PGCR * PGSPP * PG
C
      RETURN
      END
C
C
C    ************************************************************************
C    *                                                                      *
      SUBROUTINE WEAPON (N,K,PGUN,PWPN)
C    *                                                                      *
C    *  THIS IS A SUBROUTINE PROGRAM TO COMPUTE THE RELIABILITY OF A        *
C    *  WEAPONS SECTION SUBSYSTEM, K-OUT-OF-N SYSTEM WHERE K = N-1.         *
C    *                                                                      *
C    ************************************************************************
C
      INTEGER N,K,I,J,L
      REAL PGUN,PWPN,PERM,FACT,COMB
C
```

```
      IF(PGUN .GE. 1.0) THEN
         PWPN = 1.0
         RETURN
C
      ELSE
         PWPN = 0.0
C
         DO 10 I = K,N
C
            PERM = 1.0
            FACT = 1.0
c
            DO 20 J = N, N-I+1, -1
                PERM = PERM * J
   20       CONTINUE
C
            DO 30 L = I,1,-1
                FACT = FACT * L
   30       CONTINUE
c
            COMB = PERM / FACT
            PWPN = PWPN + COMB * (PGUN**I) * ((1-PGUN)**(N-I))
   10    CONTINUE
c
C     WRITE(2,*) N,K,'PWPN',PWPN
      END IF
C
      RETURN
      END
C
C
C   ********************************************************************
C   *                                                                  *
      SUBROUTINE MFDC (CRT,MFDCS,PMFSPP,PMFDC)
C   *                                                                  *
C   *  THIS IS A SUBROUTINE PROGRAM TO COMPUTE THE RELIABILITY OF A    *
C   *  FIRE DIRECTION CENTER SUBSYSTEM OF THE MODIFIED FSS.            *
C   *                                                                  *
C   ********************************************************************
C
      REAL MFDCS,PMFSPP,PMFDC,PMFCR,CRT
C
      CALL CREW (CRT,MFDCS,PMFCR)
C
      PMFDC = PMFCR * PMFSPP
C
      RETURN
      END
C
C
C   ********************************************************************
C   *                                                                  *
      SUBROUTINE CREW (CRT,S,PCREW)
C   *                                                                  *
C   *  THIS IS A SUBROUTINE PROGRAM TO COMPUTE THE RELIABILITY OF A    *
C   *  CREW COMPONENT BY THE CREW RELIABILITY FUNCTION.                *
```

```
C  *                                                                             *
C  ******************************************************************************

      REAL CRT,S,PCREW
C
      IF(S .LT. CRT) THEN
           PCREW = 0.0
           WRITE(2,*) '* SOME CREW SCORE LESS THAN CRITERION *'
C
      ELSE IF(S .GT. 100.) THEN
           WRITE(2,*) '* INPUT SCORE ERROR *'
           STOP
C
      END IF
C
      PCREW = CRT / (CRT + 100. - S)
C
      RETURN
      END
```

APPENDIX C. EFFECTS OF CREW TRAINING AND EQUIPMENT CONDITION

1. FSS reliabilities for small targets

score \ equip. rel.	1.00	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.90	0.39	0.88	0.87	0.86	0.85	0.84	0.83	0.82	0.81
100	1.00	.955	.903	.846	.786	.725	.665	.607	.550	.497	.446	.399	.355	.315	.279	.245	.215	.188	.164	.142
98	.923	.868	.810	.751	.692	.633	.576	.522	.471	.423	.378	.337	.299	.264	.233	.205	.179	.156	.136	.118
96	.835	.777	.719	.660	.604	.549	.497	.448	.403	.360	.321	.285	.252	.222	.195	.171	.149	.130	.113	.097
94	.746	.689	.632	.577	.525	.475	.428	.384	.344	.306	.272	.241	.213	.187	.164	.143	.125	.108	.094	.081
92	.661	.606	.553	.503	.455	.410	.368	.329	.294	.261	.231	.204	.180	.158	.138	.120	.105	.091	.078	.068
90	.583	.531	.483	.437	.394	.353	.316	.282	.251	.222	.197	.173	.152	.133	.116	.101	.088	.076	.066	.057
88	.512	.465	.420	.379	.340	.305	.272	.242	.215	.190	.168	.147	.129	.113	.099	.086	.074	.064	.055	.048
86	.448	.406	.366	.329	.294	.263	.234	.208	.184	.163	.143	.126	.110	.096	.084	.073	.063	.054	.047	.040
84	.392	.354	.318	.285	.255	.227	.202	.179	.158	.139	.123	.107	.094	.082	.071	.062	.054	.046	.040	.034
82	.343	.309	.277	.248	.221	.197	.174	.154	.136	.120	.105	.092	.080	.070	.061	.053	.046	.039	.034	.029
80	.300	.270	.241	.215	.192	.170	.151	.133	.117	.103	.090	.079	.069	.060	.052	.045	.039	.034	.029	.025
78	.263	.236	.210	.188	.167	.148	.131	.115	.101	.089	.078	.068	.059	.052	.045	.039	.033	.029	.025	.021
76	.230	.206	.184	.163	.145	.128	.113	.100	.088	.077	.067	.059	.051	.045	.039	.033	.029	.025	.021	.018
74	.202	.180	.161	.143	.127	.112	.099	.087	.076	.067	.058	.051	.044	.038	.033	.029	.025	.021	.018	.016
72	.177	.158	.141	.125	.111	.098	.086	.076	.066	.058	.051	.044	.038	.033	.029	.025	.021	.018	.016	.013
70	.156	.139	.123	.109	.097	.085	.075	.066	.058	.051	.044	.038	.033	.029	.025	.022	.019	.016	.014	.012
68	.137	.122	.108	.096	.085	.075	.066	.058	.051	.044	.039	.034	.029	.025	.022	.019	.016	.014	.012	.010
66	.121	.108	.095	.084	.075	.066	.058	.051	.044	.039	.034	.029	.025	.022	.019	.016	.014	.012	.010	.009
64	.107	.095	.084	.074	.066	.058	.051	.044	.039	.034	.030	.026	.022	.019	.017	.014	.012	.011	.009	.008
62	.095	.084	.074	.066	.058	.051	.045	.039	.034	.030	.026	.023	.020	.017	.015	.013	.011	.009	.008	.007
60	.084	.074	.066	.058	.051	.045	.039	.035	.030	.026	.023	.020	.017	.015	.013	.011	.009	.008	.007	.006

2. FSS reliabilities for large multiple targets

score \ equip. rel.	1.00	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.90	0.89	0.88	0.87	0.86	0.85	0.84	0.83	0.82	0.81
100	1.00	.970	.937	.899	.854	.803	.745	.682	.617	.550	.485	.422	.363	.308	.259	.216	.178	.145	.117	.094
98	.962	.924	.880	.830	.773	.712	.647	.581	.515	.452	.391	.335	.284	.238	.198	.163	.133	.107	.086	.068
96	.907	.858	.803	.742	.679	.613	.547	.483	.421	.363	.310	.262	.220	.182	.150	.122	.099	.079	.063	.050
94	.832	.774	.711	.646	.580	.515	.453	.394	.339	.289	.243	.204	.169	.139	.113	.091	.073	.058	.046	.036
92	.744	.680	.615	.550	.486	.426	.369	.317	.269	.227	.189	.157	.129	.105	.085	.068	.054	.043	.034	.026
90	.650	.585	.521	.459	.401	.346	.297	.252	.212	.177	.147	.121	.098	.080	.064	.051	.041	.032	.025	.019
88	.557	.494	.434	.378	.326	.279	.237	.199	.166	.138	.113	.092	.075	.060	.048	.038	.030	.024	.018	.014
86	.470	.412	.358	.308	.263	.223	.188	.157	.130	.107	.087	.071	.057	.046	.036	.029	.023	.018	.014	.011
84	.391	.339	.292	.249	.211	.178	.148	.123	.101	.083	.067	.054	.043	.035	.027	.022	.017	.013	.010	.008
82	.323	.278	.237	.201	.169	.141	.117	.096	.079	.064	.052	.042	.033	.026	.021	.016	.013	.010	.008	.006
80	.264	.226	.191	.161	.134	.111	.092	.075	.061	.050	.040	.032	.025	.020	.016	.012	.010	.007	.006	.004
78	.216	.183	.154	.128	.107	.088	.072	.059	.048	.039	.031	.025	.020	.015	.012	.009	.007	.006	.004	.003
76	.175	.147	.123	.102	.085	.070	.057	.046	.037	.030	.024	.019	.015	.012	.009	.007	.006	.004	.003	.003
74	.142	.119	.099	.082	.067	.055	.045	.036	.029	.023	.019	.015	.012	.009	.007	.006	.004	.003	.003	.002
72	.115	.095	.079	.065	.053	.043	.035	.028	.023	.018	.014	.011	.009	.007	.006	.004	.003	.003	.002	.001
70	.093	.077	.063	.052	.042	.034	.028	.022	.018	.014	.011	.009	.007	.005	.004	.003	.003	.002	.001	.001
68	.075	.062	.051	.041	.034	.027	.022	.018	.014	.011	.009	.007	.005	.004	.003	.003	.002	.002	.001	.001
66	.060	.050	.041	.033	.027	.022	.017	.014	.011	.009	.007	.005	.004	.003	.003	.002	.002	.001	.001	.001
64	.049	.040	.033	.027	.022	.017	.014	.011	.009	.007	.006	.004	.003	.003	.002	.002	.001	.001	.001	.001
62	.039	.032	.026	.021	.017	.014	.011	.009	.007	.006	.004	.003	.003	.002	.002	.001	.001	.001	.001	.000
60	.032	.026	.021	.017	.014	.011	.009	.007	.006	.004	.003	.003	.002	.002	.001	.001	.001	.001	.000	.000

APPENDIX D. FSS RELIABILITY VARIATION BY CREW TYPE

(All equipments and other crew types are perfect for small target mission)

SCORE	FO, FDC	GUN
100	1.000000000	1.000000000
98	0.967741907	0.985685885
96	0.937500000	0.950507820
94	0.909090877	0.903157949
92	0.882352889	0.849427462
90	0.857142806	0.793138564
88	0.833333313	0.736775219
86	0.810810804	0.681911767
84	0.789473653	0.629504800
82	0.769230723	0.580092788
80	0.750000000	0.533935547
78	0.731707275	0.491104603
76	0.714285672	0.451554596
74	0.697674394	0.415163279
72	0.681818128	0.381763875
70	0.666666627	0.351165593
68	0.652173877	0.323168814
66	0.638297856	0.297572553
64	0.625000000	0.274181366
62	0.612244844	0.252808452
60	0.599999964	0.233279765

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